EE 232 Lightwave Devices
Lecture 14-2: Strained Quantum Well Laser

Reading: Chuang, Sec. 10.4
(There is also a good discussion in Coldren, Appendix 11)

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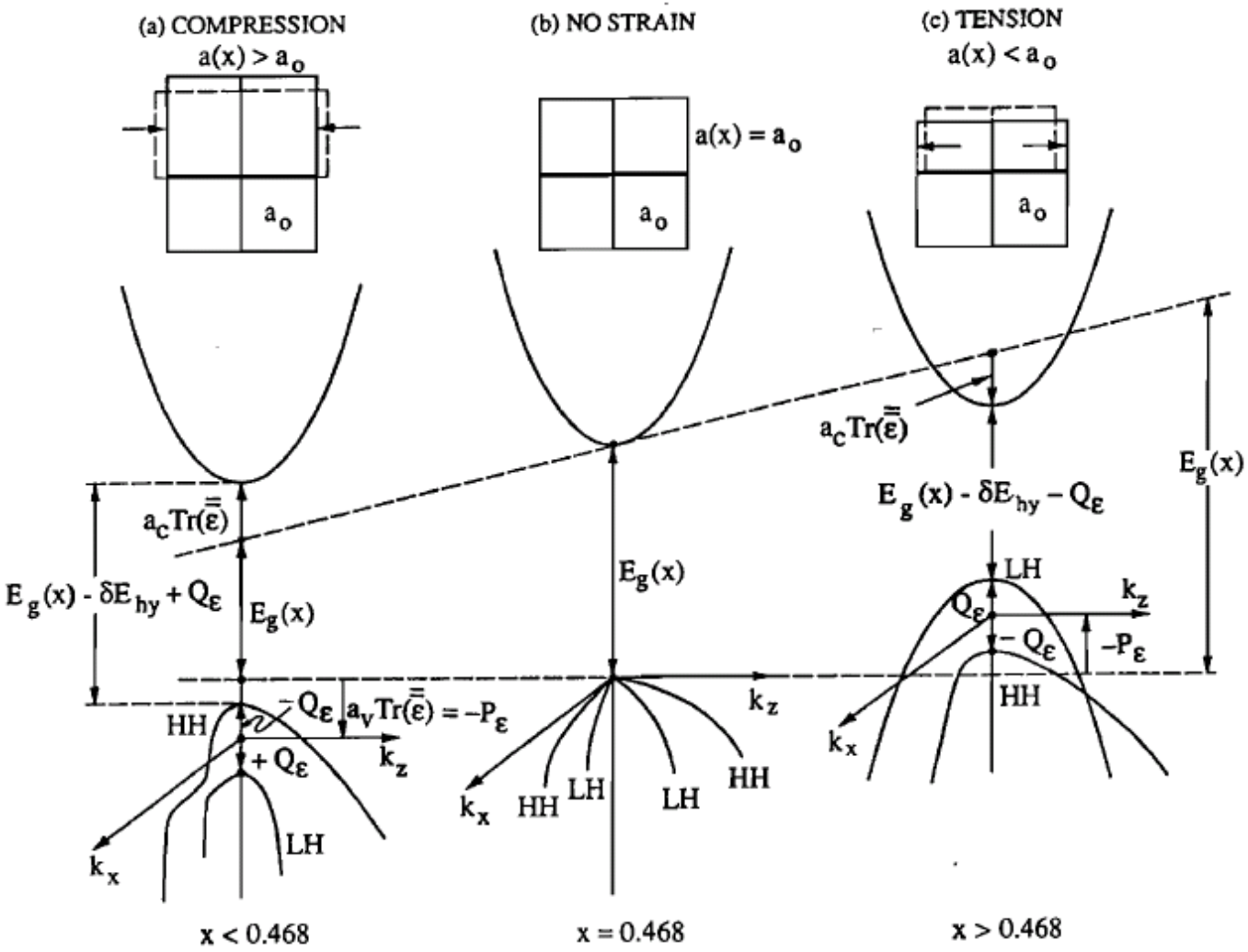
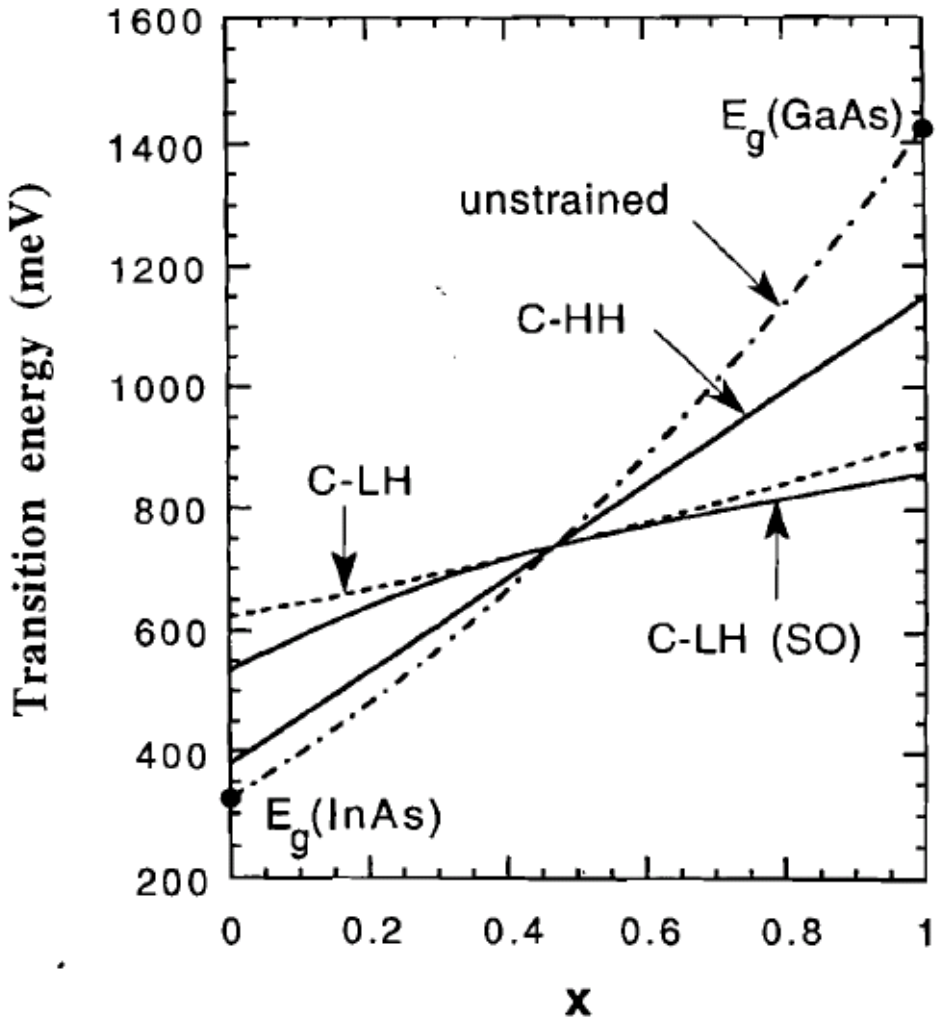
Energy Band Structure for Strained GaInAs



The energy-band structure in the momentum space for a bulk $Ga_xIn_{1-x}As$ material under (a) biaxial compression, (b) lattice-matched condition, and (c) biaxial tension for different Ga mole fractions *x*. *The heavy-hole band is above the light-hole band and its effective* mass in the transverse plane (the *k_x or k_y direction) is lighter than that of the light-hole band in* the compressive strain case in (a). The light-hole band shifts above the heavy-hole band in the case of tension in (c).

Energy Band Gap for Strained GaInAs



The energy band gap of a bulk $In_{1-x}Ga_xAs$ vs. the Ga mole fraction *x:* _._, unstrained $In_{1-x}Ga_xAs$; -, transition energies from the conduction band (C) to the heavy-hole (HH) and light-hole (LH) bands for a bulk $In_{1-x}Ga_xAs$ pseudomorphically grown on InP; ---, the conduction to light-hole transition energy calculated without the spin-orbit (SO) split-off band coupling.

E-k Relation and Effective Masses

$$P_\varepsilon = -a_V(\varepsilon_{xx}+\varepsilon_{yy}+\varepsilon_{zz}) = -2a_V\left(1-\frac{C_{12}}{C_{11}}\right)\varepsilon$$

$$Q_\varepsilon = -\frac{b}{2}(\varepsilon_{xx}+\varepsilon_{yy}-2\varepsilon_{zz}) = -b\left(1+2\frac{C_{12}}{C_{11}}\right)\varepsilon$$

$a = a_C - a_V$: hydrostatic potential

b : shear potential

$$E_{HH}(k) = -P_\varepsilon - Q_\varepsilon - \frac{\hbar^2}{2m_0}\left[(\gamma_1+\gamma_2)k_t^2 + (\gamma_1-2\gamma_2)k_z^2\right]$$

$$E_{LH}(k) = -P_\varepsilon + Q_\varepsilon - \frac{\hbar^2}{2m_0}\left[(\gamma_1-\gamma_2)k_t^2 + (\gamma_1+2\gamma_2)k_z^2\right]$$

$$m_{hh}^z = \frac{m_0}{\gamma_1-2\gamma_2} \qquad m_{hh}^t = \frac{m_0}{\gamma_1+\gamma_2}$$

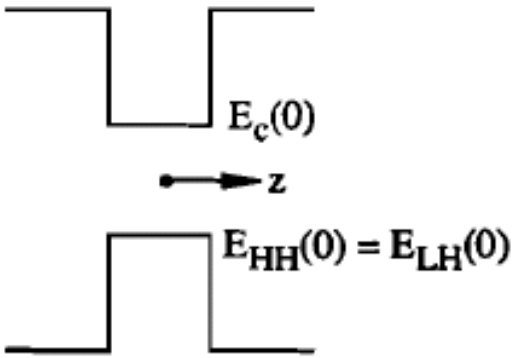
$$m_{lh}^z = \frac{m_0}{\gamma_1+2\gamma_2} \qquad m_{lh}^t = \frac{m_0}{\gamma_1-\gamma_2}$$

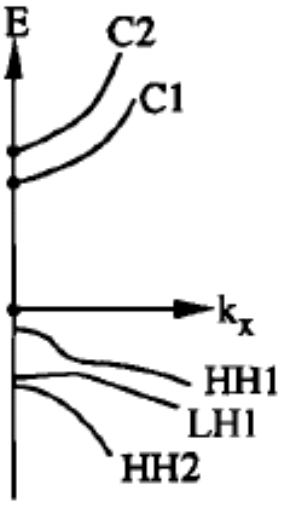
Table K.2 Important Band Structure Parameters[a–f] for GaAs, AlAs, InAs, InP, and GaP

	Materials				
	GaAs	AlAs	InAs	InP	GaP
Parameters					
a_0 (Å)	5.6533	5.6600	6.0584	5.8688	5.4505
E_g (eV)					
0 K	1.519	3.13	0.42	1.424	2.90
		2.229*			2.35*
300 K	1.424	3.03	0.354	1.344	2.78
		2.168*			2.27*
Δ (eV)	0.34	0.28	0.38	0.11	0.08
$E_{v,\mathrm{av}}$ (eV)	−6.92	−7.49	−6.67	−7.04	−7.40
Optical matrix parameter E_p (eV)	25.7 (25.0)[f]	21.1	22.2	20.7 (16.7)[f]	22.2
Deformation potentials (eV)					
a_c (eV)	−7.17	−5.64	−5.08	−5.04	−7.14
a_v (eV)	1.16	2.47	1.00	1.27	1.70
$a = a_c - a_v$ (eV)	−8.33	−8.11	−6.08	−6.31	−8.83
b (eV)	−1.7	−1.5	−1.8	−1.7	−1.8
d (eV)	−4.55	−3.4	−3.6	−5.6	−4.5
C_{11} (10^{11} dyne/cm^2)	11.879	12.5	8.329	10.11	14.05
C_{12} (10^{11} dyne/cm^2)	5.376	5.34	4.526	5.61	6.203
C_{44} (10^{11} dyne/cm^2)	5.94	5.42	3.96	4.56	7.033
Effective masses					
m_e^*/m_0	0.067	0.15	0.023	0.077	0.25
m_{hh}^*/m_0	0.50	0.79	0.40	0.60	0.67
m_{lh}^*/m_0	0.087	0.15	0.026	0.12	0.17
$m_{hh,z}/m_0 = \dfrac{1}{\gamma_1 - 2\gamma_2}$	0.333	0.478	0.263	0.606	0.326
$m_{lh,z}/m_0 = \dfrac{1}{\gamma_1 + 2\gamma_2}$	0.094	0.208	0.027	0.121	0.199
γ_1	6.8 (6.85)	3.45	20.4	4.95	4.05
γ_2	1.9 (2.1)	0.68	8.3	1.65	0.49
γ_3	2.73 (2.9)	1.29	9.1	2.35	1.25

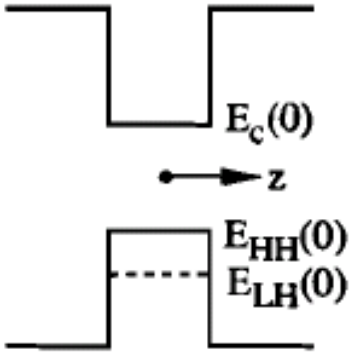
Band-Edge Profile and Subband Dispersion

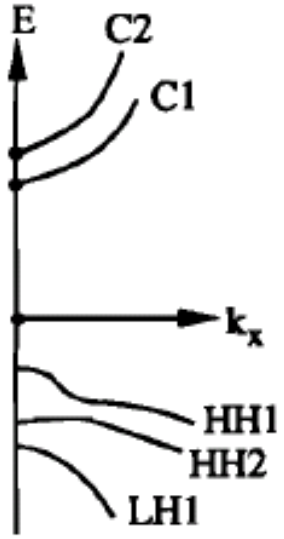
(b) An unstrained quantum well



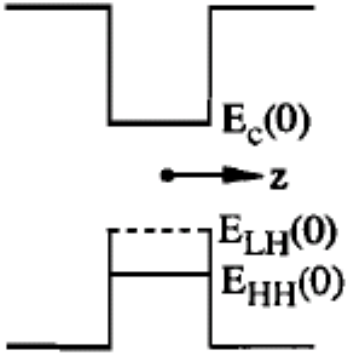


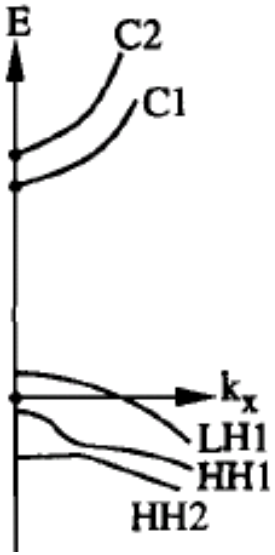
(a) A quantum well under a compressive strain





(c) A quantum well under a tensile strain





Use longitudial effective mass to calculate the quantum well levels

$$\text{HH: } m_{hh}^{z} = \frac{m_0}{\gamma_1 - 2\gamma_2}, \quad \text{LH: } m_{lh}^{z} = \frac{m_0}{\gamma_1 + 2\gamma_2}$$

Use transverse effective mass to calculate 2-d density of states, gain, etc.

$$\text{HH: } m_{hh}^{t} = \frac{m_0}{\gamma_1 + \gamma_2}, \quad \text{LH: } m_{lh}^{t} = \frac{m_0}{\gamma_1 - \gamma_2}$$